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In-air tensile load-strain behaviour of HDPE geogrids under cyclic loading

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Abstract

The knowledge of geosynthetics mechanical behaviour under static and cyclic loads is important in order to develop constitutive models to be used in numerical analyses of geosynthetic reinforced structures.
The paper describes a series of wide-width monotonic and multistage tensile tests on HDPE extruded uniaxial geogrids with different tensile stiffness. The cyclic tensile tests have been performed using a multistage procedure varying the pre-stress tensile load, the cyclic tensile loading amplitude and the frequency. The influence of these parameters on the residual strains (defined as the strain value when cyclic loads returns to the pre-stress load) has been analysed.
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Keywords: geosynthetics; soil-reinforcement; cyclic; geogrids

1. Introduction

The use of geosynthetics to improve the soil mechanical behaviour is a common practice in geotechnical engineering applications.

In-isolation monotonic tensile tests allow characterizing the tensile behaviour of geosynthetic reinforcements under static conditions, using standard procedures [1]. However, in the case of reinforced earth structures built in seismic zones, geogrids can be eventually subjected to dynamic loads in addition to the monotonic load acting under service

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load conditions. The above-mentioned standard tests do not take into account the behaviour of the geosynthetic materials under cyclic or dynamic loads.

Numerical methods are increasingly used to predict the actual behaviour of geosynthetic reinforced soil structures. To use this numerical approach requires knowledge of the constitutive model that should be adopted for reinforcement and soil, along with definition of the interface model [2-16]. In the last three decades several authors [17-23] have carried out experimental studies on the tensile properties and parameters of geosynthetics under cyclic loads. This knowledge is important in order to implement the hysteretic models in numerical codes.

The cyclic loadings acting on earth structures reinforced with viscous polymeric materials such as HDPE could result in accumulation of strain reaching an unacceptable serviceability condition. The paper describes the mechanical behaviour in terms of residual strains of two uniaxial extruded geogrids produced from high-density polyethylene (HDPE) and designed with function of soil reinforcement.

Nomenclature

A	Cyclic tensile loading amplitude (kN/m)
$\varepsilon_{max(ISO)}$	Tensile strain for Tmax (monotonic test at 20% per min strain rate, [1]) (%)
ε_r	Residual strain caused by cyclic loading (%)
ε'	Strain rate (% per min)
f	Frequency of cyclic load (Hz)
GGR1	Extruded Geogrid used in the current research
GGR2	Extruded Geogrid used in Moraci and Montanelli [19,25]
$J_{sec\ 2\%(ISO)}$	Secant tensile stiffness at 2% strain (20% per min strain rate, [1]) (kN/m)
P_i	Pre-stress tensile load in monotonic conditions (kN/m)
T_{max}	Maximum tensile strength per unit width (monotonic test at 0.2% per min strain rate) (kN/m)
$T_{max(ISO)}$	Maximum tensile strength per unit width (monotonic test at 20% per min strain rate, [1]) (kN/m)
T_{nom}	Nominal tensile strength per unit width of geosynthetic (value declared by the manufacturer) (kN/m)

2. Test procedure and specimens

The geosynthetic studied in the paper is a HDPE extruded uniaxial geogrid (referred to as GGR1). The behaviour of GGR1 has been investigated by means of wide-width monotonic and multistage tensile tests, using an in-isolation tensile test apparatus essentially composed of hydraulic clamps, a hydraulic actuator system integrated with a PC data acquisition and a control unit. The nominal tensile strength declared by the manufacturer is T_{nom}=120 kN/m.

The monotonic tensile tests have been performed using index test procedures [1] at constant strain rate (CSR) equal to ε'=20% per minute, at T=20±2°C and RH=65+5%. Since HDPE shows a strong time-dependence, meaning that stress loading rates have effect on the tensile behaviour [24], additional monotonic tests at CSR equal to ε'=0.2% per minute have been carried out.

Cyclic tensile tests have been performed (at the same temperature and humidity condition of the monotonic tests) using a multistage procedure (MS) consisting of three steps [4,9]: a) monotonic stage at CSR=0.2% per minute, reaching a fixed pre-stress load P_i chosen as percentage of the maximum tensile strength per unit width, T_{max}, obtained at the same CSR; b) cyclic stage using a sinusoidal function with a fixed, controlled loading amplitude A (chosen as T_{max} percentage) and frequency f (0.01, 0.1 and 1 Hz), for a fixed number of cycles N; c) post-cyclic stage at CSR=0.2% per minute, until specimen rupture occurs.

Cyclic loads can be considered equivalent to repetitive loads on site caused by traffic, train loading or earthquakes.

The MS tensile tests (26 in total) have been carried out ranging pre-stress load P_i from 6% to 50% of T_{max} and cyclic loading amplitude A from 8% to 52% of T_{max}.

Residual strains caused by cyclic loading (i.e. the strain value when cyclic load returns to the pre-stress load P_i) for each unload-reload cycle have been calculated, investigating the influence of pre-stress load P_i, loading amplitude A and cycles number N. Moreover, in order to study the influence of geogrid's tensile stiffness, GGR1 results have been compared with those obtained by Moraci and Montanelli [19] for a similar HDPE geogrid (GGR2) tested by using the same laboratory procedure. In table 1 the results of the monotonic tensile tests carried out at CSR equal to 20% per min and 0.2% per min are listed.

In the following, some of the main research results are showed, normalizing A and P_i with respect to T_{max}.

Table 1. Monotonic tensile test results for the geogrids used in the current research (GGR1) and in Moraci and Montanelli [19,25] (GGR2).

Geogrid	Structure	T_{nom} [kN/m]	$T_{max(ISO)}$ [kN/m] (ε'=20% per min)	$\varepsilon_{max(ISO)}$ [%] (ε'=20% per min)	$J_{2\%(ISO)}$ [kN/m] (ε'=20% per min)	T_{max} [kN/m] (ε'=0.2% per min)
GGR1	Extruded uniaxial	120	159.0	12.2	2454	103.5
GGR2	Extruded uniaxial	80	91.8	14.4	1642	60.9

3. Discussion on cyclic results

Figure 1 (a-d) shows the residual strain ε_r obtained for GGR1 referring to specific loading cycles — (a) N=1, (b) N=10, (c) N=100, (d) N=1000 — and f=0.1 Hz versus normalised loading amplitude A for different analysed classes of P_i/T_{max}. The trend suggests that residual strain ε_r increases with increasing normalized loading amplitude A at the same investigated frequency. Moreover, during the early loading cycles (Fig. 1a) ε_r seems scarcely dependent on the normalised pre-stress load P_i, while this dependence becomes evident with increasing number of cycles for higher loading amplitudes. In the range of investigated values, the experimental results show that ε_r varies from 0.1% to 1.3% in the first loading cycle; at N=10 ε_r ranges from 0.2% to 3.0%; at N=100 ε_r ranges from 0.4% to 5.0%; and at N=1000 ε_r ranges from 0.5% to 8.3%.

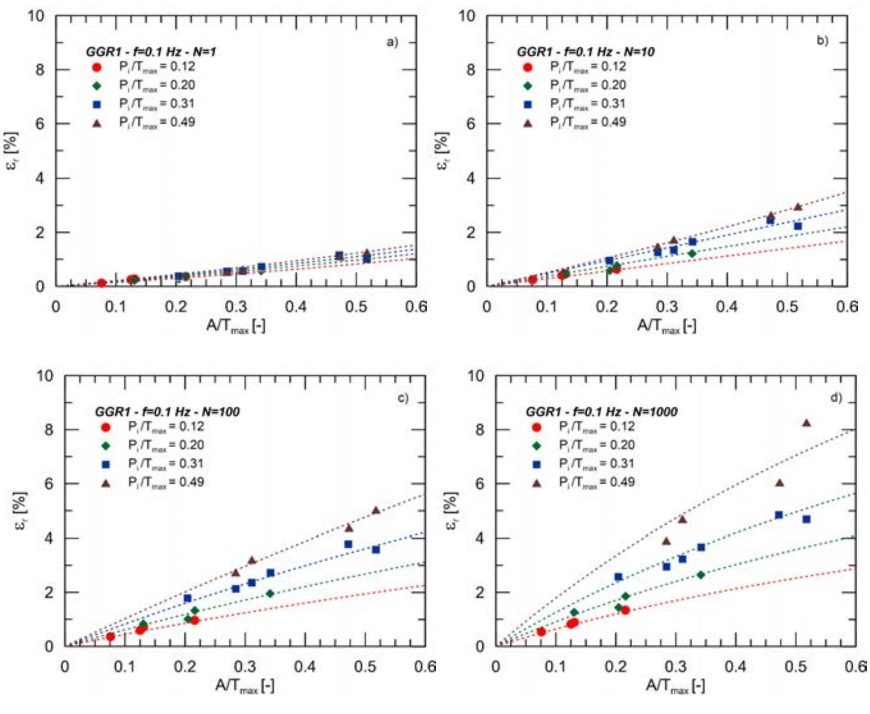

Fig. 1. GGR1 residual strains with varying normalised loading amplitudes, for different ranges of normalised pre-stress loads and f=0.1 Hz, at numbers of loading cycles N=1 (a); N=10 (b); N=100 (c); and N=1000 (d).

Figure 2a-c shows the values of residual strains obtained for GGR1 with varying frequencies for different analysed classes of A/T_{max} and for a fixed, normalised pre-stress load (P_i/T_{max}≈0.31). The graphs refer to numbers of loading cycles (a) N=1, (b) N=10, and (c) N=100. It is possible to observe that the residual strains decrease with increasing frequency for all loading amplitudes and numbers of cycles and, f being equal, increase with increasing A. At the lower frequencies, the residual strains are higher due to the creep component that increases with increasing loading time.

The typical behaviour of the HDPE materials under constant test rate shows a decreasing stiffness with increasing loading level. Moreover, HDPE exhibits a viscous-plastic behaviour meaning that it is very sensitive to the variation of test rate. Specifically, it is possible to notice a strong increase of stiffness with increasing test rate.

For lower numbers of cycles the average strain rate exponentially increases with increasing frequency, thus entailing residual strains that scarcely increase with increasing loading amplitude for the higher frequency (Fig. 2a). Once number of cycles increases (Fig. 2c) the average strain rate remains quite low for all the investigated frequencies, therefore the strain behaviour changes in trend for the higher cyclic loading level: the residual strain increments increase with increasing frequency.

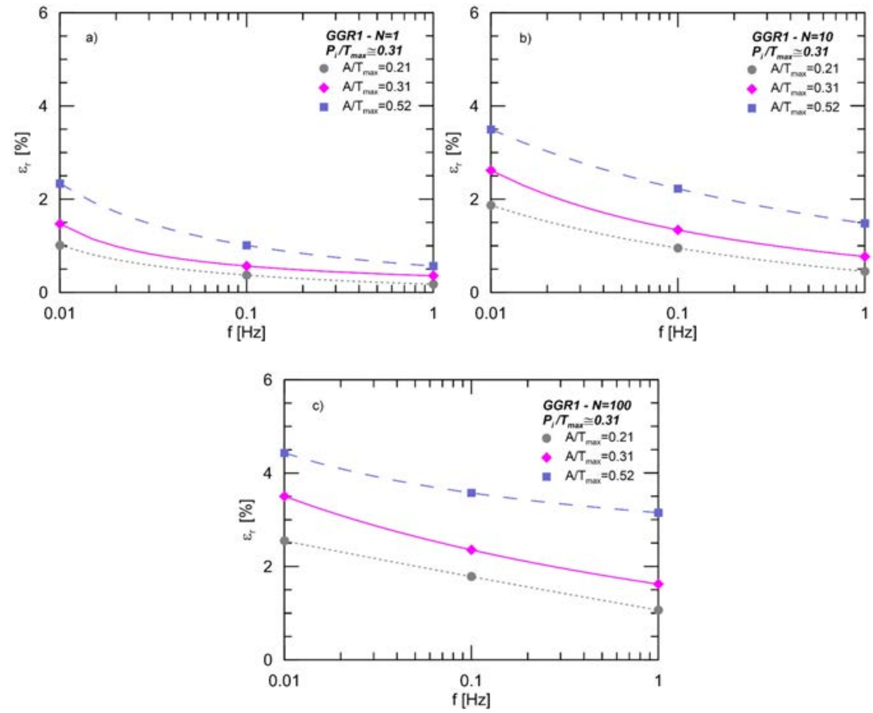

Fig. 2. GGR1 residual strains versus frequency, for a fixed normalised pre-stress load class and for different ranges of normalised loading amplitudes at numbers of loading cycles N=1 (a); N=10 (b); N=100 (c).

The influence of stiffness on the tensile behaviour of HDPE geogrids has also been investigated. The ratio between the secant tensile stiffness values (at 2% strain) $J_{sec\ 2\%(ISO)}$ obtained for the two geogrids is equal to 1.49.

The graphs in Figure 3a-d, referring to f=0.1 Hz, illustrate the residual strains obtained for GGR1 and GGR2 with varying normalised pre-stress load for a fixed, normalised loading amplitude (A/T_{max}≈0.24). The trend for both geogrids is similar, showing that the residual strains increase with increasing normalised pre-stress load level and number of cycles, but the magnitude is quite different.

For all investigated loading cycles, the tensile stiffness of the geogrid becomes increasingly important with increasing pre-stress load level: (i) the differences in terms of residual strains are very small when the cyclic load is applied without pre-stress load P_i and (ii) these differences become important for the highest normalised pre-stress load level (P_i/T_{max}=0.53). Specifically, for P_i/T_{max}=0.53, they are equal to 1.9% at *N*=1; 4.0% at *N*=10; 4.1 at *N*=100; 4.3 at *N*=1000; therefore, exceeding first ten cycles, these values scarcely increase. The variation of stiffness between GGR2 and GGR1 entails a percentage reduction of residual strain ranging from 76.0% to 48.3% when the number of cycles increases from *N*=1 to *N*=1000, the trend being linear for varying N on a logarithmic scale.

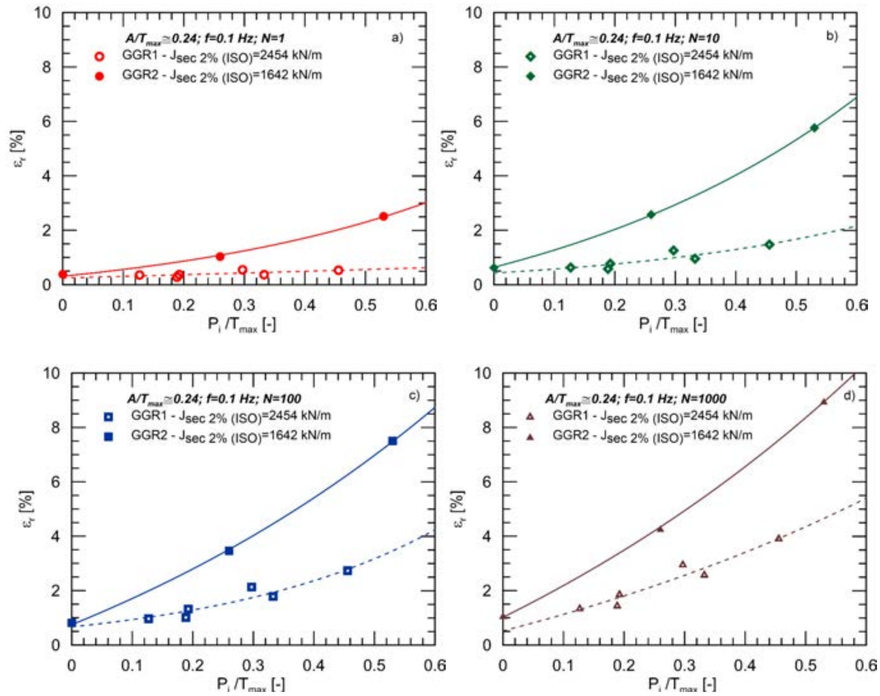

Fig. 3. GGR1 and GGR2 residual strains with varying normalised pre-stress loads, for a fixed, normalised loading amplitude and *f*=0.1 Hz, at numbers of loading cycles *N*=1 (a); *N*=10 (b); *N*=100 (c); and *N*=1000 (d).

4. Conclusions

The cyclic loadings acting in addition to the monotonic service load on reinforced earth structures could result in accumulation of excessive strains for the serviceability condition. The knowledge of the constitutive model that should be adopted for reinforcement is important in order to predict the actual behaviour of the structures, implementing the hysteretic models in numerical codes.

The wide-width monotonic and multistage tensile tests presented in this paper have shown the influence of different parameters (pre-stress load, cyclic loading amplitude, number of cycles, frequency and geogrid stiffness) on the tensile behaviour of HDPE extruded geogrids, leading to the following results in terms of residual strains:

- referring to a fixed frequency, the residual strain ε_r increases with increasing normalized loading amplitude *A*; it seems to be scarcely dependent on the normalised pre-stress load level during the early loading cycles, but for higher loading amplitudes this dependence becomes more evident with increasing number of cycles;
- residual strains ε_r decrease with increasing frequency for all loading amplitudes and numbers of cycles and, *f* being equal, increase with increasing *A*. At the lower frequencies, for a fixed number of cycles, the residual strains are

higher because the loading time is higher. For lower numbers of cycles the average strain rate exponentially increases with increasing frequency: this implicates that residual strains scarcely increase with increasing loading amplitude for the higher frequency;

- for all loading cycles, the influence of the geogrid tensile stiffness is low for the lower investigated pre-stress load values, while it becomes increasingly important with increasing P_i level. The variation of stiffness between GGR2 and GGR1 (with $J_{sec\ 2\%(ISO)}$ for GGR1 almost 50% greater than $J_{sec\ 2\%(ISO)}$ for GGR2) entails a linear reduction of residual strain for varying N on a logarithmic scale ranging from 76.0% to 48.3% with increasing number of cycles from N=1 to N=1000.

References

[1] EN ISO 10319: *Geosynthetics Wide-width Tensile Test*. International Organization for Standardization, Geneva, Switzerland; 2015.
[2] N. Moraci, G. Cardile. Pull-out behaviour of different geosynthetics embedded in granular soils. *Proceeding of the 4th Asian Regional Conference on Geosynthetics*. Shanghai, China (2008) 146-150.
[3] C.-N. Liu, J.G. Zornberg, T.-C. Chen, Y.-H. Ho, B.-H. Lin. Behavior of geogrid-sand interface in direct shear mode. *J geotech geoenviron eng* 135(12) (2009)1863-1871.
[4] N. Moraci, G. Cardile. Influence of cyclic tensile loading on pullout resistance of geogrids embedded in a compacted granular soil. *Geotext Geomembranes* 27(6) (2009) 475-487.
[5] E.M. Palmeira. Soil–geosynthetic interaction: Modelling and analysis. *Geotext Geomembranes* 27(5) (2009) 368-390.
[6] A.C.C.F. Sieira, D.M.S. Gerscovich, A.S.F.J. Sayao. Displacement and load transfer mechanisms of geogrids under pullout condition. *Geotext Geomembranes* 27(4) (2009) 241-253.
[7] N. Dixon. Soil-geosynthetic interaction: interface behaviour. *Proceeding of the 9th International Conference on Geosynthetics*. International Geosynthetics Society Guaruja, Brazil (2010) 563-582.
[8] D. Cazzuffi, L.S. Calvarano, G. Cardile, N. Moraci, P. Recalcati. European experience in pullout tests: The influence of geogrid's geometry and structure on interface behaviour. *Geosynthetics* 29(5) (2011) 42-51.
[9] N. Moraci, G. Cardile. Deformative behaviour of different geogrids embedded in a granular soil under monotonic and cyclic pullout loads. *Geotext Geomembranes* 32(1) (2012) 104-110.
[10] J. Zhou, J.-F. Chen, J.-F. Xue, J.-Q. Wang. Micro-mechanism of the interaction between sand and geogrid transverse ribs. *Geosynth Int* 19(6) (2012) 426-437.
[11] L.S. Calvarano, D. Gioffrè, G. Cardile, N. Moraci. A stress transfer model to predict the pullout resistance of extruded geogrids embedded in compacted granular soils. *Proceeding of the 10th International Conference on Geosynthetics*, ICG 2014. Berlin, Germany (2014) Code 110984.
[12] G. Cardile, L.S. Calvarano, D. Gioffrè, N. Moraci. Experimental evaluation of the pullout active length of different geogrids. *Proceeding of the 10th International Conference on Geosynthetics*, ICG 2014. Berlin, Germany (2014) Code 110984.
[13] D. Cazzuffi, N. Moraci, L.S. Calvarano, G. Cardile, D. Gioffrè, P. Recalcati. The influence of vertical effective stress and of geogrid length on interface behaviour under pullout conditions. *Geosynthetics* 32(2) (2014) 40-50.
[14] N. Moraci, D. Cazzuffi, L.S. Calvarano, G. Cardile, D. Gioffrè, P. Recalcati. The influence of soil type on interface behavior under pullout conditions. *Geosynthetics* 32(3) (2014) 42-50.
[15] G. Cardile, N. Moraci, L.S. Calvarano. Geogrid pullout behaviour according to the experimental evaluation of the active length. *Geosynth Int* 23(3) (2016) 194-205.
[16] F.-Y. Liu, P. Wang, X. Geng, J. Wang, X. Lin. Cyclic and post-cyclic behaviour from sand–geogrid interface large-scale direct shear tests. *Geosynth Int* 23(2) (2016) 129-139.
[17] R.J. Bathurst, Z. Cai. In-Isolation cyclic load-extension behavior of two geogrids. *Geosynth Int* 1(1) (1994) 1-19.
[18] A.K. Ashmawy, P.L. Bourdeau. Response of a woven and a nonwoven geotextile to monotonic and cyclic simple tension. *Geosynth Int* 3(4) (1996) 493–515.
[19] N. Moraci, F. Montanelli. Behavior of geogrids under cyclic loads. *Proceeding of the Geosynthetics '97*. Long Beach, CA, USA (1997) 961-976.
[20] H.I. Ling, Y. Mohri, T. Kawabata. Tensile properties of geogrids under cyclic loadings. *J geotech geoenviron eng* 124(8) (1998) 782-787.
[21] W. Kongkitkul, D. Hirakawa, F. Tatsuoka, T. Uchimura. Viscous deformation of geosynthetic reinforcement under cyclic loading conditions and its model simulation. *Geosynth Int* 11(2) (2004) 73-99.
[22] H. Zanzinger, H. Hangen, D. Alexiew. Fatigue behaviour of a PET-Geogrid under cyclic loading. *Geotext Geomembranes* 28(3) (2010) 251-261.
[23] C.S. Vieira, M.d.L. Lopes. Effects of the loading rate and cyclic loading on the strength and deformation properties of a geosynthetic. *Constr Build Mater* 49 (2013) 758-765.
[24] D. Hirakawa, W. Kongkitkul, F. Tatsuoka, T. Uchimura. Time-dependent stress–strain behaviour due to viscous properties of geogrid reinforcement. *Geosynth Int* 10(6) (2003) 176-199.
[25] N. Moraci, F. Montanelli. Short and Long Term Behavior of Geogrids Under Static and Cyclic Load. Earth Reinforcement Practice, *Proceedings of the International Symposium on Earth Reinforcement Practice*, Ochiai et al. editors, Balkema pub., Fukuoka, Kyushu, Japan (1996) 117-122